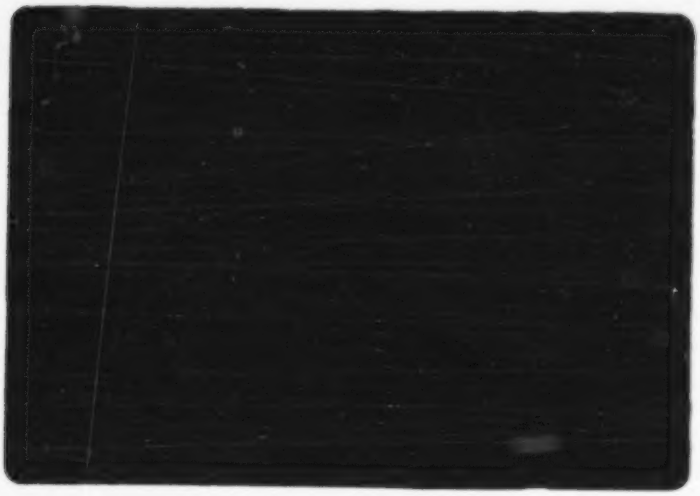
AGRICULTURAL
ENERGY CENTRE



90-03938/

IRRIGATION
PUMPING PLANT
EVALUATION

interim report

Report no. 89 - 2301 **May 1989**

Additional copies of this report are available from:

Agricultural Energy Centre
Guelph Agriculture Centre
P. O. Box 1030
Guelph, Ontario.
N1H 6N1

IRRIGATION
PUMPING PLANT
EVALUATION

interim report

Report no. 89 - 2301 **May 1989**

By: D. L. Van Hooren P.Ag.
Agricultural Energy Specialist
Agricultural Energy Centre
Ontario Ministry of Agriculture and Food
Research Station
Delhi, Ontario.

INTRODUCTION

Irrigators often inquire about the cost-effectiveness of utilizing a more economical fuel energy source to operate their irrigation power units. Changing fuel sources involves modifying the existing irrigation power unit to operate on the proposed fuel or, if this is not possible, the existing power unit must be replaced with one that operates on the proposed fuel source (this might also necessitate switching the gear head).

The Agricultural Energy Centre of the Ontario Ministry of Agriculture and Food responded to this query from irrigators by conducting on-farm irrigation pumping tests to determine the fuel efficiency and fuel consumption cost of power units operating on diesel, gasoline, natural gas or electricity. The tests were conducted during June and July of 1987 and 1988 at 15 farm sites that were applying water to tobacco crops.

Each irrigation system monitored was usually unique: few systems had identical motors and pumps (this combination usually referred to as a pumping plant). In addition, the distance between the water source and the discharge, as well as the method of application and rate of discharge, usually differed between irrigation systems. Because of these differences, the fuel efficiency of each pumping plant was calculated from the relationship between the useful work produced by the pump (output water power, kW) and the amount of fuel consumed (input power) to produce this work.

The University of Nebraska has established standards for pumping plant fuel efficiencies. These were used as a guide to determine if the pumping plants monitored were operating at peak fuel efficiency. Estimates of the amount of fuel that could be saved by improving the fuel efficiency of the pumping plants operating below the Nebraska standard were determined.

In addition, potential fuel savings resulting from switching fuel sources was investigated. Equivalent fuel energy values were used to determine the fuel consumption of a proposed fuel source that was then compared against the fuel consumption of the present fuel source.

The mention of manufacturer's trade names is for the purpose of specific product description and does not indicate endorsement or criticism of that product or products not mentioned by the author or the Ontario Ministry of Agriculture and Food.

METHOD

Test Procedure

On-farm testing of irrigation pumping plants involved determining the rate at which fuel was consumed by each power unit as well as the useful work produced by its pumping unit. This provided the information necessary to calculate each pumping plant's fuel efficiency, in the form of output water power per input power. In addition, it also provided enough information to determine each pumping plant's fuel cost to irrigate tobacco crops.

The irrigation pumping plants tested were selected at random. The pumping units of all the systems tested were of the horizontal centrifugal type. Each test required about 2 hours to conduct. Measurements included in each test were as follows:

i.) Rate of Fuel Consumption - Power units fuelled by gasoline or diesel were monitored using a similar method. The fuel supply line from the power unit was immersed in a container full of fuel. In the case of diesel powered units, the fuel return line was also immersed in the container of fuel. The container was situated on a weigh scale and a stop watch was used to determine the fuel consumption rate. Mass to volume calculations were then used to determine the fuel flowrate in litres per hour (L/h).

The fuel consumption of power units fuelled by natural gas was determined with a stop watch used to time the number of revolutions of the fastest rotating dial on the existing gas meter supplying the power unit. This procedure was repeated 3 times to determine an average flowrate. Included in the flowrate calculation was a meter correction factor which was provided by the gas company. The gas flowrate was calculated in cubic metres per hour (m^3/h).

The fuel consumption of electric power units was also determined with a stop watch used to time the revolutions of the horizontal rotating disk on the existing kWh meter supplying the power unit. Ontario Hydro provided the conversion factors for calculating the kiloWatt-hour per hour (kWh/h) consumption for each kWh meter monitored.

ii.) Pumping Flowrate - An ultrasonic flowmeter, "Detflow, Det 72L", was used to determine water flowrate. The flow meter uses the Doppler principle for its operation. Two piezo-electric transducers, connected via coaxial

cables to the meter, are mounted diametrically opposite each other on the outside of an irrigation pipe. One transducer emits a constant frequency soundwave while the other transducer receives the signal. When water flows in the irrigation pipe, the transmitting signal is altered and the frequency received is proportional to the relative velocity of the water between the transmitting and receiving trasducers. The received signal is then fed into the meter which processes the signal and indicates the water's velocity in feet per second. The inside diameter of the irrigation pipe was used in the calculations to convert the velocity reading to a flowrate in litres per second (L/s).

iii.) Total Dynamic Head - The total operating or dynamic head (tdh) for each irrigation system tested was determined. Tdh can be defined as the sum of static head plus pressure head plus friction head plus velocity head. Tdh can be derived from the sum of the head equivalent of the gauge pressure reading at the pump plus the suction lift. For each pumping test conducted, the pressure reading at pumping unit was recorded and the suction lift (vertical distance between the water level and the pump discharge) was measured with an inclinometer. Tdh was then calculated in kiloPascals (kPa).

Fuel Efficiency

The output water power generated by each pumping unit, in Watts (W), was derived from multiplying tdh (kPa) by the pumping flowrate (L/s). The fuel efficiency (kW-h/fuel input) of the pumping plant was then calculated by dividing the output water power by the input power (fuel consumed per hour).

Nebraska Standard

Table 1 indicates standard fuel efficiencies of various fuelled pumping plants as suggested by the University of Nebraska. The fuel efficiencies are based on a centrifugal pump with an efficiency of 75% and various efficiencies for different fuelled power units.

The standard fuel efficiencies in table 1 were used as a guide to rate the irrigation pumping plants monitored and to determine if the pumping plants were operating at optimum efficiency.

RESULTS AND EVALUATION

Pumping Plant Fuel Efficiency

Table 2 is a summary of the data collected for each pumping test conducted. The output power generated by the pumping units ranged from a low of 12.20 kW to a high of 34.40 kW, with the majority in the range of 18 to 22 kW. The range in fuel efficiencies of the different fuelled pumping plants monitored are as follows: diesel - 1.39 to 2.55 kW-h/L, electric - 0.40 to 0.76 kW-h/kWh, gasoline - 0.68 to 1.25 kW-h/L and natural gas - 1.13 and 1.19 kW-h/m^3.

Information provided in table 3 is an estimate of the fuel consumption and cost to apply 25 mm of water to 1 ha for each of the pumping plants monitored. Fuel consumption is in the order of 30.73 to 50.92 L for diesel, 80.48 to 176.34 kWh for electric, 40.38 to 67.00 L for gasoline and 39.80 m^3 and 45.79 m^3 for natural gas. Based on 1988 fuel prices, fuel costs range from $9.68 to $16.04 for diesel, $4.90 to $10.74 for electric, $13.93 to $23.12 for gasoline and $7.16 and $8.24 for natural gas.

It should be noted that the fuel prices used to calculate the information in table 3 were supplied by local fuel suppliers in July of 1988. Tax rebates from the Federal and Provincial governments, in effect in 1988, are included in the prices for diesel and gasoline.

Monitored Fuel Efficiency Compared to Nebraska Standard

Table 4 indicates the fuel efficiencies of the pumping plants tested as a percentage of the standard fuel efficiencies for pumping plants suggested by the University of Nebraska. Rated as a percentage of the Nebraska standard, the different fuelled pumping plants tested were operating at 57 to 104% for diesel, 61 to 115% for electric, 40 to 73% for gasoline, and 68% and 64% for natural gas.

Most irrigation extension specialists suggest that if a pumping plant's measured efficiency is 80 to 90% of the Nebraska standard then corrective action may be considered, however, if the measured efficiency is less than 80% of the Nebraska standard then corrective action should definitely be taken. Twelve of the 15 pumping plants monitored have efficiencies less than 80% of the Nebraska standard. Below average fuel efficiency can be attributed to one or more of the following: 1.) an oversized pump and/or power unit; 2.) wear and/or changes in adjustment of the pump's impellers; or 3.) a power unit in need of a tune-up.

If the fuel efficiencies of the pumping plants monitored were improved to match the Nebraska fuel efficiencies, fuel consumption would be reduced. The potential fuel and cost savings are indicated in table 5. Fuel savings to apply 25 mm of water to 1 ha for the different fuelled power units monitored would be in the order of 7.27 to 21.90 L for diesel, 15.58 to 68.77 kWh for electric, 10.90 to 40.20 L for gasoline and 12.74 m^3 and 16.48 m^3 for natural gas. Based on 1988 fuel prices, the fuel cost savings would be $2.29 to $6.90 for diesel, $0.95 to $4.19 for electric, $3.76 to $13.87 for gasoline and $2.29 and $2.97 for natural gas.

Changing Fuel Sources

Improving the fuel efficiency of the pumping plant is not the only method to reduce costs. An alternate is to operate on a more economical fuel source which requires either modifying the existing power unit or replacing the existing power unit. Table 6 indicates the fuel energy equivalent of operating on another fuel and is often used to determine the consumption of a proposed fuel source. To use this table, one locates the proposed fuel source on the left side of the table and then moves across the table to the column indicating the present fuel source. At this intersection a conversion factor is indicated. The present fuel consumption is then multiplied by this conversion factor to determine the equivalent fuel consumption for the proposed fuel source.

Table 7 indicates the fuel consumption and cost savings if the gasoline fuelled power units monitored were modified to operate on propane or natural gas. The fuel savings when 25 mm of water are applied to 1 ha would range from $3.76 to $5.43 on propane and $7.31 to $10.55 on natural gas.

Table 7 also indicates the fuel consumption and cost savings that would result from replacing the gasoline fuelled power units monitored with either diesel or electric fuelled power units. The fuel savings when 25 mm of water are applied to 1 ha would range from $5.12 to $8.49 on diesel and $7.57 to $12.57 on electricity.

CONCLUSIONS

Based on the evaluations of the pumping plants tested, the majority of pumping plants were operating below the Nebraska standard. Fuel savings can be achieved by either improving the fuel efficiency of the existing pumping plant or switching to a cheaper fuel source.

It should be noted, however, that modifying an existing power unit

to operate on a different fuel or replacing the existing power unit with one that operates on another fuel (which may necessitate changing the gear head) require a capital expenditure. Thus, prior to making any changes to an existing power unit, a breakeven analysis must be calculated to determine if fuel savings will payback the capital expense in a reasonable period of time.

RECOMMENDATIONS

It is recommended that the pumping tests be continued in 1989 since a relatively small number of pumping tests were conducted in 1987 and 1988. This would ensure that the fuel efficiency and fuel cost calculated for the different fuelled pumping plants is representative of the majority of pumping plants used to irrigate tobacco.

ACKNOWLEDGEMENTS

The author extends a special thanks to all of the tobacco producers who participated in the pumping plant tests and to Al Ratavicius for assisting in monitoring and evaluating the pumping plant tests.

Table 1: Nebraska standards for average fuel efficiency of irrigation pumping plants

FUEL Source	POWER Unit Eff.	PUMP Unit Eff.*	OVERALL Pumping Plant Eff.	AVERAGE FUEL EFFICIENCY OF PUMPING PLANTS (kilowatt-hours per unit of fuel)
diesel	30.67%	75%	23%	2.46 kW-h/L
electricity	88.00%	75%	66%	0.66 kW-h/kWh
gasoline	22.67%	75%	17%	1.71 kW-h/L
natural gas	22.67%	75%	17%	1.76 kW-h/m^3

Source: Schroeder, M. A. 1982. Using the Nebraska pumping plant performance criteria. Irrigation Pumping Plant Performance Handbook. Agricultural Engineering Department, Cooperative Extension Service, Institute of Agriculture and Natural Resources. University of Nebraska - Lincoln, Lincoln, Nebraska.

*A well designed irrigation pump is normally 70 to 80% efficient.

Table 2: Pumping plant data

Test #	POWER UNIT fuel type	POWER UNIT fuel consumption (per hour)	PUMP UNIT type*	PUMP UNIT tdh (kPa)	PUMP UNIT flow (L/s)	PUMP UNIT output power (kW)	FUEL EFFICIENCY
	Diesel						
1.		10.26 L	c	907	21.56	19.55	1.91 kW-h/L
2.		10.98 L	c	957	21.56	20.63	1.88 kW-h/L
3.		13.48 L	c	1130	30.44	34.40	2.55 kW-h/L
4.		14.35 L	c	877	23.74	20.82	1.45 kW-h/L
5.		14.27 L	c	818	26.09	21.34	1.50 kW-h/L
6.		15.29 L	c	1021	20.83	21.27	1.39 kW-h/L
	Electric						
7.		38.67 kWh	c	1016	15.22	15.46	0.40 kW-h/kWh
8.		39.07 kWh	c	875	33.76	29.54	0.76 kW-h/kWh
9.		52.64 kWh	c	1194	25.85	30.86	0.59 kW-h/kWh
	Gasoline						
10.		16.73 L	c	871	21.74	18.94	1.13 kW-h/L
11.		17.33 L	c	742	25.91	19.23	1.11 kW-h/L
12.		17.82 L	c	660	18.48	12.20	0.68 kW-h/L
13.		19.99 L	c	724	34.43	24.93	1.25 kW-h/L
	Natural Gas						
14.		15.25 m^3	c	679	26.64	18.09	1.19 kW-h/m^3
15.		16.01 m^3	c	744	24.28	18.06	1.13 kW-h/m^3

*c - centrifugal pump

Table 3: Fuel consumption and cost to apply 25 mm of water to 1 ha for pumping plants monitored.

Test #	PUMPING PLANT			FUEL INPUT TO APPLY 25 mm to 1ha	
	fuel type	fuel consumption (per hour)	water flowrate (L/s)	consumption	cost*
	Diesel				
1.		10.26 L	21.56	33.04 L	$10.41
2.		10.98 L	21.56	35.36 L	$11.14
3.		13.48 L	30.44	30.73 L	$ 9.68
4.		14.35 L	23.74	42.05 L	$13.24
5.		14.27 L	26.09	37.96 L	$11.96
6.		15.29 L	20.83	50.92 L	$16.04
	Electric				
7.		38.67	15.22	176.34 kWh	$10.74
8.		39.07	33.76	80.43 kWh	$ 4.90
9.		52.64	25.85	141.60 kWh	$ 8.62
	Gasoline				
10.		16.73 L	21.74	53.37 L	$18.41
11.		17.33 L	25.91	46.44 L	$16.02
12.		17.82 L	18.48	67.00 L	$23.12
13.		19.99 L	34.43	40.38 L	$13.93
	Natural Gas				
14.		15.25 m^3	26.64	39.80 m^3	$ 7.16
15.		16.01 m^3	24.28	45.79 m^3	$ 8.24

*July 1988 fuel prices - $0.315/L diesel, $0.0609/kWh electric, $0.345/L gasoline, $0.18/$m^3$ natural gas (diesel and gasoline prices include Federal and Provincial tax rebate)

Table 4: Fuel efficiency of the pumping plants tested as a percentage of the Nebraska standard

Test #	PUMPING PLANTS fuel type	fuel efficiency	fuel efficiency as % of Nebraska Standard*
	Diesel		
1.		1.91 kW-h/L	78
2.		1.88 kW-h/L	76
3.		2.55 kW-h/L	104
4.		1.45 kW-h/L	59
5.		1.50 kW-h/L	61
6.		1.39 kW-h/L	57
	Electric		
7.		0.40 kW-h/kWh	61
8.		0.76 kW-h/kWh	115
9.		0.59 kW-h/kWh	89
	Gasoline		
10.		1.13 kW-h/L	66
11.		1.11 kW-h/L	65
12.		0.68 kW-h/L	40
13.		1.25 kW-h/L	73
	Natural Gas		
14.		1.19 kW-h/m^3	68
15.		1.13 kW-h/m^3	64

*Nebraska standards from table 1

Table 5: Fuel and cost savings if pumping plants tested were operating at Nebraska standard

Test #	PUMPING PLANTS fuel type	fuel eff. as % of Nebraska std.	FUEL INPUT TO APPLY 25 mm to 1 ha @ PRESENT FUEL EFF. consumption	cost*	@ NEBRASKA STD. consumption	cost	DIFF. consumption	cost
	Diesel							
1.		78	33.04 L	$10.41	25.77 L	$8.12	7.27 L	$2.29
2.		76	35.36 L	$11.14	26.87 L	$8.46	8.49 L	$2.67
3.		104	30.73 L	$ 9.68	----	----	----	----
4.		59	42.05 L	$13.24	24.81 L	$7.82	17.24 L	$5.43
5.		61	37.96 L	$11.96	23.16 L	$7.30	14.80 L	$4.66
6.		57	50.92 L	$16.04	29.02 L	$9.14	21.90 L	$6.90
	Electric							
7.		61	176.34 kWh	$10.74	107.57 kWh	$6.55	68.77 kWh	$4.19
8.		115	80.48 kWh	$ 4.90	----	----	----	----
9.		89	141.60 kWh	$ 8.62	126.02 kWh	$ 7.67	15.58 kWh	$0.95
	Gasoline							
10.		66	53.37 L	$18.41	35.22 L	$12.15	18.15 L	$6.26
11.		65	46.44 L	$16.02	30.19 L	$10.42	16.25 L	$5.61
12.		40	67.00 L	$23.12	26.80 L	$ 9.25	40.20 L	$13.87
13.		73	40.38 L	$13.93	29.48 L	$10.17	10.90 L	$3.76
	Natural Gas							
14.		68	39.80 m^3	$ 7.16	27.06 m^3	$ 4.87	12.74 m^3	$2.29
15.		64	45.79 m^3	$ 8.24	29.31 m^3	$ 5.28	16.48 m^3	$2.97

*fuel prices indicated below table 3

Table 6: Fuel energy equivalents

PROPOSED ENERGY SOURCE	PRESENT ENERGY SOURCE				
	diesel (L)	gasoline (L)	propane (L)	natural gas (m^3)	electricity (kWh)
diesel (L)	1	0.693	0.551	0.662	0.268
gasoline (L)	1.443	1	0.796	0.960	0.387
propane (L)	1.814	1.257	1	1.199	0.486
natural gas (m^3)	1.511	1.042	0.834	1	0.394
electricity (kWh)	3.731	2.585	2.057	2.538	1

Source: Dorn, T. W. 1982. Selecting the most economical energy source for irrigation pumping. Irrigation Pumping Plant Performance Handbook. Agricultural Engineering Department, Cooperative Extension Service, Institute of Agriculture and Natural Resources. University of Nebraska - Lincoln, Lincoln, Nebraska.

Table 7: Fuel savings resulting from switching fuel sources to apply 25 mm of water to 1 ha

Test #	PUMPING PLANTS fuel type	L	$	ESTIMATED FUEL INPUT ON OTHER FUELS* propane** L	$	(diff.)***	natural gas m^3	$	(diff.)	diesel L	$	(diff.)	electric kWh	$	(diff.)
10.	gasoline	53.37	18.41	67.09	14.09	($4.32)	55.61	10.01	($ 8.40)	36.99	11.65	($6.76)	137.96	8.40	($10.00)
11.	gasoline	46.44	16.02	58.38	12.26	($3.76)	48.39	8.71	($ 7.31)	32.18	10.14	($5.88)	120.05	7.31	($ 8.71)
12.	gasoline	67.00	23.12	84.22	17.69	($5.43)	69.81	12.57	($10.55)	46.43	14.63	($8.49)	173.20	10.55	($12.57)
13.	gasoline	40.38	13.93	50.76	10.66	($3.27)	42.08	7.57	($ 6.36)	27.98	8.81	($5.12)	104.38	6.36	($ 7.57)

* derived from fuel energy equivalent values in table 6

** propane price of $0.21/L, all other prices indicated below table 3

***gasoline cost minus cost on another fuel type